

really a diamond, there is nothing like it known to man!"

"Nothing indeed," said he.

She sat staring at the great piece of glowing mineral which lay in her hand. Its surface was irregular; it had many faces; the subdued light from the window gave it the appearance of animated water. He felt it necessary to speak.

"Even these little pieces," he said, "are most valuable jewels."

She still sat silent, looking at the glowing object she held.

"You see, these are not like the stones which are found in our diamond-fields," he said. "Those, most likely, were little unconsumed bits of the original mass, afterwards gradually forced up from the interior in the same way that many metals and minerals are forced up, and then rounded and dulled by countless ages of grinding and abrasion, due to the action of rocks or water."

"Roland," she cried, excitedly, "this is riches beyond imagination! What is common wealth to what you have discovered? Every living being on earth could—"

"Ah, Margaret," he interrupted, "do not let your thoughts run that way. If my discovery should be put to the use of which you are thinking, it would bring poverty, not wealth, to the world, and not

a diamond on earth would be worth more than a common pebble. Everywhere, in civilized countries and in barbaric places, people would see their riches vanish before them as if it had been blighted by the touch of an evil magician."

She trembled. "And these, are they to be valued as common pebbles?"

"Oh no," said he; "so long as that great shaft is mine, these broken fragments are to us riches far ahead of our wildest imaginations."

"Roland," she cried, "are you going down into that shaft for more of them?"

"Never, never, never again," he said. "What we have here is enough for us, and if I were offered all the good that there is in this world which money cannot buy, I would never go down into that cleft again. There was one moment when I stood in that cave in which an awful terror shot into my soul which I shall never be able to forget. In the light of my electric lamps sent through a vast transparent mass I could see nothing, but I could feel. I put out my foot, and I found it was upon a sloping surface. In another instant I might have slid—where? I cannot bear to think of it!"

She threw her arms around him and held him tightly.

[TO BE CONTINUED.]

THE CENTURY'S PROGRESS IN CHEMISTRY.

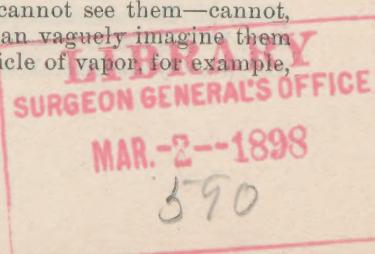
BY HENRY SMITH WILLIAMS, M.D.

I.

SMALL beginnings have great endings—sometimes. As a case in point, note what came of the small original effort of a self-trained back-country Quaker youth named John Dalton, who along toward the close of the last century became interested in the weather, and was led to construct and use a crude rain-gauge to test the amount of the waterfall. The simple experiments thus inaugurated led to no fewer than two hundred thousand recorded observations regarding the weather, which formed the basis for some of the most epochal discoveries in meteorology, as we have seen. But this was only a beginning. The simple rain-gauge pointed the way to the most important generalization of our century in a field of science with which, to

the casual observer, it might seem to have no alliance whatever. The wonderful theory of atoms, on which the whole gigantic structure of modern chemistry is founded, was the logical outgrowth, in the mind of John Dalton, of those early studies in meteorology.

The way it happened was this: From studying the rainfall, Dalton turned naturally to the complementary process of evaporation. He was soon led to believe that vapor exists in the atmosphere as an independent gas. But since two bodies cannot occupy the same space at the same time, this implies that the various atmospheric gases are really composed of discrete particles. These ultimate particles are so small that we cannot see them—cannot, indeed, more than vaguely imagine them—yet each particle of vapor, for example,



is just as much a portion of water as if it were a drop out of the ocean, or, for that matter, the ocean itself. But again, water is a compound substance, for it may be separated, as Cavendish had shown, into the two elementary substances hydrogen and oxygen. Hence the atom of water must be composed of two lesser atoms joined together. Imagine an atom of hydrogen and one of oxygen. Unite them, and we have an atom of water; sever them, and the water no longer exists; but whether united or separate the atoms of hydrogen and of oxygen remain hydrogen and oxygen and nothing else. Differently mixed together or united, atoms produce different gross substances; but the elementary atoms never change their chemical nature—their distinct personality.

It was about the year 1803 that Dalton first gained a full grasp of the conception of the chemical atom. At once he saw that the hypothesis, if true, furnished a marvellous key to secrets of matter hitherto insoluble—questions relating to the relative proportions of the atoms themselves. It is known, for example, that a certain bulk of hydrogen gas unites with a certain bulk of oxygen gas to form water. If it be true that this combination consists essentially of the union of atoms one with another (each single atom of hydrogen united to a single atom of oxygen), then the relative weights of the original masses of hydrogen and of oxygen must be also the relative weights of each of their respective atoms. If one pound of hydrogen unites with five and one-half pounds of oxygen (as, according to Dalton's experiments, it did), then the weight of the oxygen atom must be five and one-half times that of the hydrogen atom. Other compounds may plainly be tested in the same way: Dalton made numerous tests before he published his theory. He found that hydrogen enters into compounds in smaller proportions than any other element known to him, and so, for convenience, determined to take the weight of the hydrogen atom as unity. The atomic weight of oxygen then becomes (as given in Dalton's first table of 1803) 5.5; that of water (hydrogen plus oxygen) being of course 6.5. The atomic weights of about a score of substances are given in Dalton's first paper, which was read before the Literary and Philosophical Society of Manchester, October 21,

1803. I wonder if Dalton himself, great and acute intellect though he had, suspected, when he read that paper, that he was inaugurating one of the most fertile movements ever entered on in the whole history of science?

II.

Be that as it may, it is certain enough that Dalton's contemporaries were at first little impressed with the novel atomic theory. Just at this time, as it chanced, a dispute was waging in the field of chemistry regarding a matter of empirical fact which must necessarily be settled before such a theory as that of Dalton could even hope for a hearing. This was the question whether or not chemical elements unite with one another always in definite proportions. Berthollet, the great co-worker with Lavoisier, and now the most authoritative of living chemists, contended that substances combine in almost indefinitely graded proportions between fixed extremes. He held that solution is really a form of chemical combination—a position which, if accepted, left no room for argument.

But this contention of the master was most actively disputed, in particular by Louis Joseph Proust, and all chemists of repute were obliged to take sides with one or the other. For a time the authority of Berthollet held out against the facts, but at last accumulated evidence told for Proust and his followers, and toward the close of the first decade of our century it came to be generally conceded that chemical elements combine with one another in fixed and definite proportions.

More than that. As the analysts were led to weigh carefully the quantities of combining elements, it was observed that the proportions are not only definite, but that they bear a very curious relation to one another. If element A combines with two different proportions of element B to form two compounds, it appeared that the weight of the larger quantity of B is an exact multiple of that of the smaller quantity. This curious relation was noticed by Dr. Wollaston, one of the most accurate of observers, and a little later it was confirmed by Johan Jakob Berzelius, the great Swedish chemist, who was to be a dominating influence in the chemical world for a generation to come. But this combination of elements in numerical proportions was exactly what Dalton had

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noticed as early as 1802, and what had led him directly to the atomic weights. So the confirmation of this essential point by chemists of such authority gave the strongest confirmation to the atomic theory.

During these same years the rising authority of the French chemical world, Joseph Louis Gay-Lussac, was conducting experiments with gases, which he had undertaken at first in conjunction with Humboldt, but which later on were conducted independently. In 1809, the next year after the publication of the first volume of Dalton's *New System of Chemical Philosophy*, Gay-Lussac published the results of his observations, and among other things brought out the remarkable fact that gases, under the same conditions as to temperature and pressure, combine always in definite numerical proportions as to volume. Exactly two volumes of hydrogen, for example, combine with one volume of oxygen to form water. Moreover, the resulting compound gas always bears a simple relation to the combining volumes. In the case just cited the union of two volumes of hydrogen and one of oxygen results in precisely two volumes of water vapor.

Naturally enough the champions of the atomic theory seized upon these observations of Gay-Lussac as lending strong support to their hypothesis—all of them, that is, but the curiously self-reliant and self-sufficient author of the atomic theory himself, who declined to accept the observations of the French chemist as valid. Yet the observations of Gay-Lussac were correct, as countless chemists since then have demonstrated anew, and his theory of combination by volumes became one of the foundation-stones of the atomic theory, despite the opposition of the author of that theory.

The true explanation of Gay-Lussac's law of combination by volumes was thought out almost immediately by an Italian savant, Amadeo Avogadro, and expressed in terms of the atomic theory. The fact must be, said Avogadro, that under similar physical conditions every form of gas contains exactly the same number of ultimate particles in a given volume. Each of these ultimate physical particles may be composed of two or more atoms (as in the case of water vapor), but such a compound atom conducts itself as if it were a simple and indivisible atom,

as regards the amount of space that separates it from its fellows under given conditions of pressure and temperature. The compound atom, composed of two or more elementary atoms, Avogadro proposed to distinguish, for purposes of convenience, by the name molecule. It is to the molecule, considered as the unit of physical structure, that Avogadro's law applies.

This vastly important distinction between atoms and molecules, implied in the law just expressed, was published in 1811. Four years later, the famous French physicist Ampère outlined a similar theory, and utilized the law in his mathematical calculations. And with that the law of Avogadro dropped out of sight for a full generation. Little suspecting that it was the very key to the inner mysteries of the atoms for which they were seeking, the chemists of the time cast it aside, and let it fade from the memory of their science.

This, however, was not strange, for of course the law of Avogadro is based on the atomic theory, and in 1811 the atomic theory was itself still being weighed in the balance. The law of multiple proportions found general acceptance as an empirical fact; but many of the leading lights of chemistry still looked askance at Dalton's explanation of this law. Thus Wollaston, though from the first he inclined to acceptance of the Daltonian view, cautiously suggested that it would be well to use the non-committal word "equivalent" instead of "atom"; and Davy, for a similar reason, in his book of 1812, speaks only of "proportions," binding himself to no theory as to what might be the nature of these proportions.

At least two great chemists of the time, however, adopted the atomic view with less reservation. One of these was Thomas Thomson, professor at Edinburgh, who in 1807 had given an outline of Dalton's theory in a widely circulated book, which first brought the theory to the general attention of the chemical world. The other, and even more noted advocate of the atomic theory, Johan Jakob Berzelius. This great Swedish chemist at once set to work to put the atomic theory to such tests as might be applied in the laboratory. He was an analyst of the utmost skill, and for years he devoted himself to the determination of the combining weights, "equivalents," or "proportions" of the different elements. These

determinations, in so far as they were accurately made, were simple expressions of empirical facts, independent of any theory; but gradually it became more and more plain that these facts all harmonize with the atomic theory of Dalton. So by common consent the proportionate combining weights of the elements came to be known as atomic weights—the name Dalton had given them from the first—and the tangible conception of the chemical atom as a body of definite constitution and weight gained steadily in favor.

From the outset the idea had had the utmost tangibility in the mind of Dalton. He had all along represented the different atoms by geometrical symbols—as a circle for oxygen, a circle enclosing a dot for hydrogen, and the like—and had represented compounds by placing these symbols of the elements in juxtaposition. Berzelius proposed to improve upon this method by substituting for the geometrical symbol the initial of the Latin name of the element represented—O for oxygen, H for hydrogen, and so on—a numerical coefficient to follow the letter as an indication of the number of atoms present in any given compound. This simple system soon gained general acceptance, and with slight modifications it is still universally employed. Every schoolboy now is aware that H_2O is the chemical way of expressing the union of two atoms of hydrogen with one of oxygen to form a molecule of water. But such a formula would have had no meaning for the wisest chemist before the day of Berzelius.

The universal fame of the great Swedish authority served to give general currency to his symbols and atomic weights, and the new point of view thus developed led presently to two important discoveries, which removed the last lingering doubts as to the validity of the atomic theory. In 1819 two French physicists, Dulong and Petit, while experimenting with heat, discovered that the specific heats of solids (that is to say, the amount of heat required to raise the temperature of a given mass to a given degree) vary inversely as their atomic weights. In the same year Eilhard Mitscherlich, a German investigator, observed that compounds having the same number of atoms to the molecule are disposed to form the same angles of crystallization—a property which he called isomorphism.

Here, then, were two utterly novel and independent sets of empirical facts which harmonize strangely with the supposition that substances are composed of chemical atoms of a determinate weight. This surely could not be coincidence—it tells of law. And so as soon as the claims of Dulong and Petit and of Mitscherlich had been substantiated by other observers, the laws of the specific heat of atoms, and of isomorphism, took their place as new levers of chemical science. With the aid of these new tools an impregnable breast-work of facts was soon piled about the atomic theory. And John Dalton, the author of that theory, plain provincial Quaker, working on to the end in semi-retirement, became known to all the world and for all time as a master of masters.

III.

During those early years of our century, when Dalton was grinding away at chemical fact and theory in his obscure Manchester laboratory, another Englishman held the attention of the chemical world with a series of the most brilliant and widely heralded researches. Humphry Davy had come to London in 1801, at the instance of Count Rumford, to assume the chair of chemical philosophy in the Royal Institution, which the famous American had just founded.

Here, under Davy's direction, the largest voltaic battery yet constructed had been put in operation, and with its aid the brilliant young experimenter was expected almost to perform miracles. And indeed he scarcely disappointed the expectation, for with the aid of his battery he transformed so familiar a substance as common potash into a metal which was not only so light that it floated on water, but possessed the seemingly miraculous property of bursting into flames as soon as it came in contact with that fire-quenching liquid. If this were not a miracle, it had for the popular eye all the appearances of the miraculous.

What Davy really had done was to decompose the potash, which hitherto had been supposed to be elementary, liberating its oxygen, and thus isolating its metallic base, which he named potassium. The same thing was done with soda, and the closely similar metal sodium was discovered—metals of a unique type, possessed of a strange avidity for oxygen,

and capable of seizing on it even when it is bound up in the molecules of water. Considered as mere curiosities, these discoveries were interesting, but aside from that they were of great theoretical importance, because they showed the compound nature of some familiar chemicals that had been regarded as elements. Several other elementary earths met the same fate when subjected to the electrical influence, the metals barium, calcium, and strontium being thus discovered. Thereafter Davy always referred to the supposed elementary substances (including oxygen, hydrogen, and the rest) as "undecomposed" bodies. These resist all present efforts to decompose them, but how can one know what might not happen were they subjected to an influence, perhaps some day to be discovered, which exceeds the battery in power as the battery exceeds the blow-pipe?

Another and even more important theoretical result that flowed from Davy's experiments during this first decade of the century was the proof that no elementary substances other than hydrogen and oxygen are produced when pure water is decomposed by the electric current. It was early noticed by Davy and others that when a strong current is passed through water, alkalies appear at one pole of the battery and acids at the other, and this though the water used were absolutely pure. This seemingly told of the creation of elements—a transmutation but one step removed from the creation of matter itself—under the influence of the new "force." It was one of Davy's greatest triumphs to prove, in the series of experiments recorded in his famous Bakerian lecture of 1806, that the alleged creation of elements did not take place, the substances found at the poles of the battery having been dissolved from the walls of the vessels in which the water experimented upon had been placed. Thus the same implement which had served to give a certain philosophical warrant to the fading dreams of alchemy banished those dreams peremptorily from the domain of present science.

Even though the presence of the alkalies and acids in the water was explained, however, their respective migrations to the negative and positive poles of the battery remained to be accounted for. Davy's classical explanation assumed that different elements differ among them-

selves as to their electrical properties, some being positively, others negatively, electrified. Electricity and "chemical affinity," he said, apparently are manifestations of the same force, acting in the one case on masses, in the other on particles. Electro-positive particles unite with electro-negative particles to form chemical compounds, in virtue of the familiar principle that opposite electricities attract one another. When compounds are decomposed by the battery, this mutual attraction is overcome by the stronger attraction of the poles of the battery itself.

This theory of binary composition of all chemical compounds, through the union of electro-positive and electro-negative atoms or molecules, was extended by Berzelius, and made the basis of his famous system of theoretical chemistry. This theory held that all inorganic compounds, however complex their composition, are essentially composed of such binary combinations. For many years this view enjoyed almost undisputed sway. It received what seemed strong confirmation when Faraday showed the definite connection between the amount of electricity employed and the amount of decomposition produced in the so-called electrolyte. But its claims were really much too comprehensive, as subsequent discoveries proved.

IV.

When Berzelius first promulgated his binary theory he was careful to restrict its unmodified application to the compounds of the inorganic world. At that time, and for a long time thereafter, it was supposed that substances of organic nature had some properties that kept them aloof from the domain of inorganic chemistry. It was little doubted that a so-called "vital force" operated here, replacing or modifying the action of ordinary "chemical affinity." It was, indeed, admitted that organic compounds are composed of familiar elements—chiefly carbon, oxygen, hydrogen, and nitrogen—but these elements were supposed to be united in ways that could not be imitated in the domain of the non-living. It was regarded almost as an axiom of chemistry that no organic compound whatever could be put together from its elements—synthesized—in the laboratory. To effect the synthesis of even the simplest

organic compound it was thought that the "vital force" must be in operation.

Therefore a veritable sensation was created in the chemical world when, in the year 1828, it was announced that the young German chemist Friedrich Wöhler, formerly pupil of Berzelius, and already known as a coming master, had actually synthesized the well-known organic product urea in his laboratory at Sacrow. The "exception which proves the rule" is something never heard of in the domain of logical science. Natural law knows no exceptions. So the synthesis of a single organic compound sufficed at a blow to break down the chemical barrier which the imagination of the fathers of the science had erected between animate and inanimate nature. Thenceforth the philosophical chemist would regard the plant and animal organisms as chemical laboratories in which conditions are peculiarly favorable for building up complex compounds of a few familiar elements, under the operation of universal chemical laws. The chimera "vital force" could no longer gain recognition in the domain of chemistry.

Now a wave of interest in organic chemistry swept over the chemical world, and soon the study of carbon compounds became as much the fashion as electro-chemistry had been in the preceding generation.

Foremost among the workers who rendered this epoch of organic chemistry memorable were Justus Liebig in Germany and Jean Baptiste André Dumas in France, and their respective pupils, Charles Frédéric Gerhardt and Augustus Laurent. Wöhler, too, must be named in the same breath, as also must Louis Pasteur, who, though somewhat younger than the others, came upon the scene in time to take chief part in the most important of the controversies that grew out of their labors.

Several years earlier than this the way had been paved for the study of organic substances by Gay-Lussac's discovery, made in 1815, that a certain compound of carbon and nitrogen, which he named cyanogen, has a peculiar degree of stability which enables it to retain its identity, and enter into chemical relations after the manner of a simple body. A year later Ampère discovered that nitrogen and hydrogen, when combined in certain proportions to form what he called ammonium, have the same property. Ber-

zelius had seized upon this discovery of the compound radical, as it was called, because it seemed to lend aid to his dualistic theory. He conceived the idea that all organic compounds are binary unions of various compound radicals with an atom of oxygen, announcing this theory in 1818. Ten years later, Liebig and Wöhler undertook a joint investigation which resulted in proving that compound radicals are indeed very abundant among organic substances. Thus the theory of Berzelius seemed to be substantiated, and organic chemistry came to be defined as the chemistry of compound radicals.

But even in the day of its seeming triumph the dualistic theory was destined to receive a rude shock. This came about through the investigations of Dumas, who proved that in a certain organic substance an atom of hydrogen may be removed, and an atom of chlorine substituted in its place without destroying the integrity of the original compound—much as a child might substitute one block for another in its play-house. Such a substitution would be quite consistent with the dualistic theory, were it not for the very essential fact that hydrogen is a powerfully electro-positive element, while chlorine is as strongly electro-negative. Hence the compound radical which united successively with these two elements must itself be at one time electro-positive, at another electro-negative—a seeming inconsistency which threw the entire Berzelian theory into disfavor.

In its place there was elaborated, chiefly through the efforts of Laurent and Gerhardt, a conception of the molecule as a unitary structure, built up through the aggregation of various atoms, in accordance with "elective affinities" whose nature is not yet understood. A doctrine of "nuclei" and a doctrine of "types" of molecular structure were much exploited, and, like the doctrine of compound radicals, became useful as aids to memory and guides for the analyst, indicating some of the plans of molecular construction, though by no means penetrating the mysteries of chemical affinity. They are classifications rather than explanations of chemical unions. But at least they served an important purpose in giving definiteness to the idea of a molecular structure built of atoms as the basis of all substances. Now at last the word molecule came to have a distinct mean-

ing, as distinct from "atom," in the minds of the generality of chemists, as it had had for Avogadro a third of a century before. Avogadro's hypothesis that there are equal numbers of these molecules in equal volumes of gases, under fixed conditions, was revived by Gerhardt, and a little later, under the championship of Cannizzaro, was exalted to the plane of a fixed law. Thenceforth the conception of the molecule was to be as dominant a thought in chemistry as the idea of the atom had become in a previous epoch.

V.

Of course the atom itself was in no sense displaced, but Avogadro's law soon made it plain that the atom had often usurped territory that did not really belong to it. In many cases the chemists had supposed themselves dealing with atoms as units where the true unit was the molecule. In the case of elementary gases, such as hydrogen and oxygen, for example, the law of equal numbers of molecules in equal spaces made it clear that the atoms do not exist isolated, as had been supposed. Since two volumes of hydrogen unite with one volume of oxygen to form two volumes of water vapor, the simplest mathematics shows, in the light of Avogadro's law, not only that each molecule of water must contain two hydrogen atoms (a point previously in dispute), but that the original molecules of hydrogen and oxygen must have been composed in each case of two atoms—else how could one volume of oxygen supply an atom for every molecule of two volumes of water?

What, then, does this imply? Why, that the elementary atom has an avidity for other atoms, a longing for companionship, an "affinity"—call it what you will—which is bound to be satisfied if other atoms are in the neighborhood. Placed solely among atoms of its own kind, the oxygen atom seizes on a fellow oxygen atom, and in all their mad dances these two mates cling together—possibly revolving about one another in miniature planetary orbits. Precisely the same



JOHN DALTON.

thing occurs among the hydrogen atoms. But now suppose the various pairs of oxygen atoms come near other pairs of hydrogen atoms (under proper conditions which need not detain us here), then each oxygen atom loses its attachment for its fellow, and flings itself madly into the circuit of one of the hydrogen couplets, and—presto!—there are only two molecules for every three there were before, and free oxygen and hydrogen have become water. The whole process, stated in chemical phraseology, is summed up in the statement that under the given conditions the oxygen atoms had a greater affinity for the hydrogen atoms than for one another.

As chemists studied the actions of various kinds of atoms, in regard to their unions with one another to form molecules, it gradually dawned upon them that not all elements are satisfied with the same number of companions. Some elements ask only one, and refuse to take more; while others link themselves, when occasion offers, with two, three, four, or more. Thus we saw that oxygen forsook a single atom of its own kind and linked itself with two atoms of hydrogen. Clear-

ly, then, the oxygen atom, like a creature with two hands, is able to clutch two other atoms. But we have no proof that under any circumstances it could hold more than two. Its affinities seem satisfied when it has two bonds. But, on the other hand, the atom of nitrogen is able to hold three atoms of hydrogen, and does so in the molecule of ammonium (NH_3); while the carbon atom can hold four atoms of hydrogen or two atoms of oxygen.

Evidently, then, one atom is not always equivalent to another atom of a different kind in combining powers. A recognition of this fact by Frankland about 1852, and its further investigation by others (notably A. Kekulé and A. S. Couper), led to the introduction of the word equivalent into chemical terminology in

hand with which to grasp—while oxygen has capacity for two bonds, nitrogen for three (possibly for five), and carbon for four. The words monovalent, divalent, trivalent, tetravalent, etc., were coined to express this most important fact, and the various elements came to be known as monads, diads, triads, etc. Just why different elements should differ thus in valency no one as yet knows; it is an empirical fact that they do. And once the nature of any element has been determined as regards its valency, a most important insight into the possible behavior of that element has been secured. Thus a consideration of the fact that hydrogen is monovalent, while oxygen is divalent, makes it plain that we must expect to find no more than three compounds of these two elements, namely, $\text{H}-\text{O}$ —(written HO by the chemist, and called hydroxyl); $\text{H}-\text{O}-\text{H}$ (H_2O , or water), and $\text{H}-\text{O}-\text{O}-\text{H}$ (H_2O_2 , or hydrogen peroxide). It will be observed that in the first of these compounds the atom of oxygen stands, so to speak, with one of its hands free, eagerly reaching out, therefore, for another companion, and hence, in the language of chemistry, forming an unstable compound. Again in the third compound, though all hands are clasped, yet one pair links oxygen with oxygen; and this also must be an unstable union, since the avidity of an atom for its own kind is relatively weak. Thus the well-known properties of hydrogen peroxide are explained, its easy decomposition, and the eagerness with which it seizes upon the elements of other compounds.

But the molecule of water, on the other hand, has its atoms arranged in a state of stable equilibrium, all their affinities being satisfied. Each hydrogen atom has satisfied its one affinity by clutching the oxygen atom; and the oxygen atom has both its bonds satisfied by clutching back at the two hydrogen atoms. Therefore the trio, linked in this close bond, have no tendency to reach out for any other companion, nor, indeed, any power to hold another should it thrust itself upon them. They form a "stable"



JOHAN JAKOB BERZELIUS.

a new sense, and in particular to an understanding of the affinities or "valency" of different elements, which proved of the most fundamental importance. Thus it was shown that, of the four elements that enter most prominently into organic compounds, hydrogen can link itself with only a single bond to any other element—it has, so to speak, but a single

compound, which under all ordinary circumstances will retain its identity as a molecule of water, even though the physical mass of which it is a part changes its condition from a solid to a gas—from ice to vapor.

But a consideration of this condition of stable equilibrium in the molecule at once suggests a new question: How can an aggregation of atoms, having all their affinities satisfied, take any further part in chemical reactions? Seemingly such a molecule, whatever its physical properties, must be chemically inert, incapable of any atomic readjustments. And so in point of fact it is, so long as its component atoms cling to one another unremittingly. But this, it appears, is precisely what the atoms are little prone to do. It seems that they are fickle to the last degree in their individual attachments, and are as prone to break away from bondage as they are to enter into it. Thus the oxygen atom which has just flung itself into the circuit of two hydrogen atoms, the next moment flings itself free again and seeks new companions. It is for all the world like the incessant change of partners in a rollicking dance.

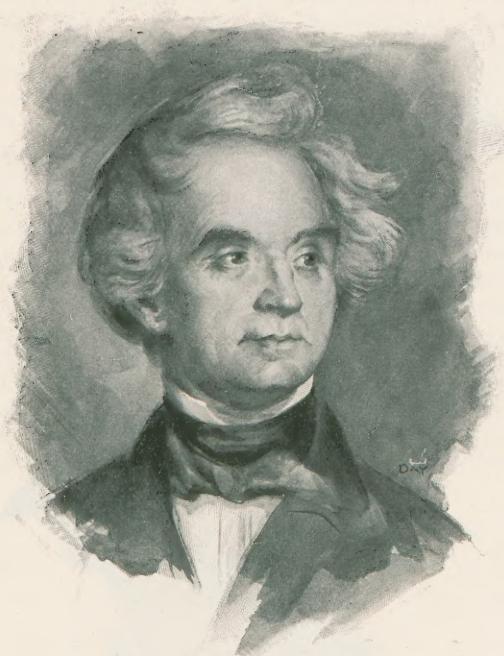
This incessant dissolution and reformation of molecules in a substance which as a whole remains apparently unchanged was first fully appreciated by Ste.-Claire Deville, and by him named dissociation. It is a process which goes on much more actively in some compounds than in others, and very much more actively under some physical conditions (such as increase of temperature) than under others. But apparently no substances at ordinary temperatures, and no temperature above the absolute zero, are absolutely free from its disturbing influence. Hence it is that molecules having all the valency of their atoms fully satisfied do not lose their chemical activity—since each atom is momentarily free in the exchange of partners, and may seize upon different atoms from its former partners, if those it prefers are at hand.

While, however, an appreciation of this ceaseless activity of the atom is essential to a proper understanding of its chemical efficiency, yet from another



JOSEPH LOUIS GAY-LUSSAC.

point of view the "saturated" molecule—that is, the molecule whose atoms have their valency all satisfied—may be thought of as a relatively fixed or stable organism. Even though it may presently be torn down, it is for the time being a completed structure; and a consideration of the valency of its atoms gives the best clew that has hitherto been obtainable as to the character of its architecture. How important this matter of architecture of the molecule—of space relations of the atoms—may be was demonstrated as long ago as 1823, when Liebig and Wöhler proved, to the utter bewilderment of the chemical world, that two substances may have precisely the same chemical constitution—the same number and kind of atoms—and yet differ utterly in physical properties. The word isomerism was coined by Berzelius to express this anomalous condition of things, which seemed to negative the most fundamental truths of chemistry. Naming the condition by no means explained it, but the fact was made clear that something besides the mere number and kind of atoms is important in the architecture of a molecule. It became certain that atoms are not thrown together haphazard to build a molecule,



JUSTUS VON LIEBIG.

any more than bricks are thrown together at random to form a house.

How delicate may be the gradations of architectural design in building a molecule was well illustrated about 1850, when Pasteur discovered that some carbon compounds—as certain sugars—can only be distinguished from one another, when in solution, by the fact of their twisting or polarizing a ray of light to the left or to the right, respectively. But no inkling of an explanation of these strange variations of molecular structure came until the discovery of the law of valency. Then much of the mystery was cleared away; for it was plain that since each atom in a molecule can hold to itself only a fixed number of other atoms, complex molecules must have their atoms linked in definitive chains or groups. And it is equally plain that where the atoms are numerous, the exact plan of grouping may sometimes be susceptible of change without doing violence to the law of valency. It is in such cases that isomerism is observed to occur.

By paying constant heed to this matter of the affinities, chemists are able to make

diagrammatic pictures of the plan of architecture of any molecule whose composition is known. In the simple molecule of water (H_2O), for example, the two hydrogen atoms must have released one another before they could join the oxygen, and the manner of linking must apparently be that represented in the graphic formula $H—O—H$. With molecules composed of a large number of atoms, such graphic representation of the scheme of linking is of course increasingly difficult, yet, with the affinities for a guide, it is always possible. Of course no one supposes that such a formula, written in a single plane, can possibly represent the true architecture of the molecule; it is at best suggestive or diagrammatic rather than pictorial. Nevertheless it affords hints as to the structure of the molecule such as the fathers of chemistry would not have thought it possible ever to attain.

VI.

These utterly novel studies of molecular architecture may seem at first sight to take from the atom much of its former prestige as the all-important personage of the chemical world. Since so much depends upon the mere position of the atoms, it may appear that comparatively little depends upon the nature of the atoms themselves. But such a view is incorrect, for on closer consideration it will appear that at no time has the atom been seen to renounce its peculiar personality. Within certain limits the character of a molecule may be altered by changing the positions of its atoms (just as different buildings may be constructed of the same bricks), but these limits are sharply defined, and it would be as impossible to exceed them as it would be to build a stone building with bricks. From first to last the brick remains a brick, whatever the style of architecture it helps to construct; it never becomes a stone. And just as closely does each atom retain its own peculiar properties, regardless of its surroundings.

Thus, for example, the carbon atom may take part in the formation at one

time of a diamond, again of a piece of coal, and yet again of a particle of sugar, of wood fibre, of animal tissue, or of a gas in the atmosphere; but from first to last—from glass-cutting gem to intangible gas—there is no demonstrable change whatever in any single property of the atom itself. So far as we know, its size, its weight, its capacity for vibration or rotation, and its inherent affinities, remain absolutely unchanged throughout all these varying fortunes of position and association. And the same thing is true of every atom of all of the sixty-odd elementary substances with which the modern chemist is acquainted. Every one appears always to maintain its unique integrity, gaining nothing and losing nothing.

All this being true, it would seem as if the position of the Daltonian atom as a primordial bit of matter, indestructible and non-transmutable, had been put to the test by the chemistry of our century, and not found wanting. Since those early days of the century when the electric battery performed its miracles and seemingly reached its limitations in the hands of Davy, many new elementary substances have been discovered, but no single element has been displaced from its position as an undecomposable body. Rather have the analyses of the chemist seemed to make it more and more certain that all elementary atoms are in truth what John Herschel called them, "manufactured articles"—primordial, changeless, indestructible.

And yet, oddly enough, it has chanced that hand in hand with the experiments leading to such a goal have gone other experiments and speculations of exactly the opposite tenor. In each generation there have been chemists among the leaders of their science who have refused to admit that the so-called elements are really elements at all in any final sense, and who have sought eagerly for proof which might warrant their scepticism. The first bit of evidence tending to support this view was furnished by an English physician, Dr. William Prout, who in

1815 called attention to a curious relation to be observed between the atomic weight of the various elements. Accepting the figures given by the authorities of the time (notably Thomson and Berzelius), it appeared that a strikingly large proportion of the atomic weights were exact multiples of the weight of hydrogen, and



GUSTAV ROBERT KIRCHHOFF.

that others differed so slightly that errors of observation might explain the discrepancy. Prout felt that this could not be accidental, and he could think of no tenable explanation, unless it be that the atoms of the various alleged elements are made up of different fixed numbers of hydrogen atoms. Could it be that the one true element—the one primal matter—is hydrogen, and that all other forms of matter are but compounds of this original substance?

Prout advanced this startling idea at first tentatively, in an anonymous publication; but afterward he espoused it openly and urged its tenability. Coming just after Davy's dissociation of some supposed elements, the idea proved al-

luring, and for a time gained such popularity that chemists were disposed to round out the observed atomic weights of all elements into whole numbers. But presently renewed determinations of the atomic weights seemed to discountenance this practice, and Prout's alleged law fell into disrepute. It was revived, however, about 1840, by Dumas, whose great authority secured it a respectful hearing, and whose careful redetermination of the weight of carbon, making it exactly twelve times that of hydrogen, aided the cause.

Subsequently Stas, the pupil of Dumas, undertook a long series of determinations of atomic weights, with the expectation of confirming the Proutian hypothesis. But his results seemed to disprove the hypothesis, for the atomic weights of many elements differed from whole numbers by more, it was thought, than the limits of error of the experiments. It is noteworthy, however, that the confidence of Dumas was not shaken, though he was led to modify the hypothesis, and, in accordance with previous suggestions of Clark and of Marignac, to recognize as

the primordial element, not hydrogen itself, but an atom half the weight, or even one-fourth the weight of that of hydrogen, of which primordial atom the hydrogen atom itself is compounded. But even in this modified form the hypothesis found great opposition from experimental observers.

In 1864, however, a novel relation between the weights of the elements and their other characteristics was called to the attention of chemists by Professor John A. R. Newlands, of London, who had noticed that if the elements are arranged serially in the numerical order of their atomic weights, there is a curious recurrence of similar properties at intervals of eight elements. This so-called "law of octaves" attracted little immediate attention, but the facts it connotes soon came under the observation of other chemists, notably of Professors Gustav Hinrichs in America, Dmitri Mendeléeff in Russia, and Lothar Meyer in Germany. Mendeléeff gave the discovery fullest expression, exposing it in 1869, under the title of "periodic law."

Though this early exposition of what has since been admitted to be a most important discovery was very fully outlined, the generality of chemists gave it little heed till a decade or so later, when three new elements, gallium, scandium, and germanium, were discovered, which, on being analyzed, were quite unexpectedly found to fit into three gaps which Mendeléeff had left in his periodic scale. In effect, the periodic law had enabled Mendeléeff to predicate the existence of the new elements years before they were discovered. Surely a system that leads to such results is no mere vagary. So very soon the periodic law took its place as one of the most important generalizations of chemical science.

This law of periodicity was put forward as an expression of observed relations independent of hypothesis; but of course the theoretical bearings of these facts could not be overlooked. As Pro-



ROBERT WILHELM BUNSEN.



LOUIS JACQUES MANDÉ DAGUERRE.

From a daguerreotype made in Paris for Meade Brothers, New York, now in possession of Abraham Bogardus, New York.

essor J. H. Gladstone has said, it forces upon us "the conviction that the elements are not separate bodies created without reference to one another, but that they have been originally fashioned, or have been built up from one another, according to some general plan." It is but a short step from that proposition to the Proutian hypothesis.

But the atomic weights are not alone in suggesting the compound nature of the alleged elements. Evidence of a totally different kind has contributed to the same end, from a source that could hardly have been imagined when the Proutian hypothesis was formulated, through the addition of a novel weapon to the armamentarium of the chemist—the spectroscope. The perfection of this instrument, in the hands of two German scientists, Gustav Robert Kirchhoff and Robert Wilhelm Bunsen, came about through the investigation, toward the middle of the century, of the meaning of the dark lines

which had been observed in the solar spectrum by Fraunhofer as early as 1815, and by Wollaston a decade earlier. It was suspected by Stokes and by Fox Talbot in England, but first brought to demonstration by Kirchhoff and Bunsen, that these lines, which were known to occupy definite positions in the spectrum, are really indicative of particular elementary substances. By means of the spectroscope, which is essentially a magnifying lens attached to a prism of glass, it is possible to locate the lines with great accuracy, and it was soon shown that here was a new means of chemical analysis of the most exquisite delicacy. It was found, for example, that the spectroscope could detect the presence of a quantity of sodium so infinitesimal as the one two-hundred-thousandth of a grain. But what was even more important, the spectroscope put no limit upon the distance of location of the substance it tested, provided only that sufficient light came from

it. The experiments it recorded might be performed in the sun, or in the most distant stars or nebulæ; indeed, one of the earliest feats of the instrument was to wrench from the sun the secret of his chemical constitution.

To render the utility of the spectroscope complete, however, it was necessary

philosophers contributed to the advancement of the new method.

In 1843 Dr. John W. Draper, the famous English-American chemist and physiologist, showed that by photography the Fraunhofer lines in the solar spectrum might be mapped with absolute accuracy; also proving that the silvered film revealed many lines invisible to the unaided eye. The value of this method of observation was recognized at once, and as soon as the spectroscope was perfected, the photographic method, in conjunction with its use, became invaluable to the chemist. By this means comparisons of spectra may be made with a degree of accuracy not otherwise obtainable; and in case of the stars, whole clusters of spectra may be placed on record at a single observation.

As the examination of the sun and stars proceeded, chemists were amazed or delighted, according to their various preconceptions, to witness the proof that many familiar terrestrial elements are to be found in the celestial bodies. But what perhaps surprised them most was to observe the enormous preponderance in the sidereal bodies of the element hydrogen. Not only are there vast quantities of this element in the sun's atmosphere, but some other suns appeared to show

hydrogen lines almost exclusively in their spectra. Presently it appeared that the stars of which this is true are those white stars, such as Sirius, which had been conjectured to be the hottest; whereas stars that are only red-hot, like our sun, show also the vapors of many other elements, including iron and other metals.

In 1878 Mr. J. Norman Lockyer, in a paper before the Royal Society, called attention to the possible significance of this series of observations. He urged that the fact of the sun showing fewer elements than are observed here on the cool earth, while stars much hotter than the sun show chiefly one element, and that one hydrogen, the lightest of known elements, seemed to give color to the possibility that our alleged elements are really compounds, which at the temperature of



JOHN W. DRAPER.

to link with it another new chemical agency, namely, photography. This now familiar process is based on the property of light to decompose certain unstable compounds of silver, and thus alter their chemical composition. We have seen that Davy and Wedgwood barely escaped the discovery of the value of the photographic method. Their successors quite overlooked it until about 1826, when Louis J. M. Daguerre, the French chemist, took the matter in hand, and after many years of experimentation brought it to relative perfection in 1839, in which year the famous daguerreotype first brought the matter to popular attention. In the same year Mr. Fox Talbot read a paper on the subject before the Royal Society, and soon afterward the efforts of Herschel and numerous other natural

the hottest stars may be decomposed into hydrogen, the latter "element" itself being also doubtless a compound, which might be resolved under yet more trying conditions.

Here, then, was what might be termed direct experimental evidence for the hypothesis of Prout. Unfortunately, however, it is evidence of a kind which only a few experts are competent to discuss—so very delicate a matter is the spectral analysis of the stars. What is still more unfortunate, the experts do not agree among themselves as to the validity of Mr. Lockyer's conclusions. Some, like Professor Crookes, have accepted them with acclaim, hailing Lockyer as "the Darwin of the inorganic world," while others have sought a different explana-

tion of the facts he brings forward. As yet it cannot be said that the controversy has been brought to final settlement. Still, it is hardly to be doubted that now, since the periodic law has seemed to join hands with the spectroscope, a belief in the compound nature of the so-called elements is rapidly gaining ground among chemists. More and more general becomes the belief that the Daltonian atom is really a compound radical, and that back of the seeming diversity of the alleged elements is a single unique form of primordial matter. But it should not be forgotten that this view, whatever its attractiveness, still lurks in the domain of theory. There is no proof that the Daltonian atom has yet been divided in the laboratory.

THE KENTUCKIANS.*

BY JOHN FOX, JR.

PART FOURTH.

XIII.

TO meet death, a rat goes to his hole, a lion to his lair; the same instinct perhaps, in the shadow of a lesser crisis even, sends a man home. Marshall took the train with Anne's face still haunting him like the face of the dead. Chance had rent the veil, and he had turned away, as he would have turned had chance as suddenly bared the girl's breast as it had seemed to bare her soul. The stupefying calm that held him broke slowly as the train rushed through the winter fields; and slowly his hold on himself began to loosen. By the time he was climbing into his buggy he was asking himself fiercely what the use of it all was; and a moment later he pulled his horse to her haunches before his club door, in answer to an old voice within him that had been still for a long while. He had always stopped there in the old days, and it was the habit of resisting the impulse since those days, perhaps, that made him suddenly lash his horse on now. The mare sprang ahead with a frightened snort, and Marshall, with a half-curse on himself for his thoughtless cruelty, called kindly to her several times to make re-

compense. Then he settled back into his big coat, and a little later he was on the white turnpike again speeding home, with his chin on his breast and the same fight in his soul that was there on that other drive, when Stallard first came into his life and into Anne's. Only the yellow evening light was almost gone now. There was not a bird-note from the darkening brown fields. The sun was a sullen blotch of fire when he reached his gate, and the woods behind the house were black and still. But his mother was waiting for him, and he was very tender with her that night. She knew something was wrong—she always knew; but she waited for him to tell, as she always did; and there were things that he had never told and could never tell, which she never knew nor guessed; and he was grateful, whatever the shame her faith and his weakness brought to him. The pantry door was open when he went to his room, but there was no glisten of glass-ware from within. That temptation had been removed long ago, and it was well for him that night that it was. His room was cold; the white moon through the window looked cold, and the dead fields and the gaunt moonlit woods. The whole

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